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INTRODUCTION

During their 10-week tenure at the U.S. Environmental Protection Agency (EPA), the 1997 AAAS-EPA Environmental Science and Engineering Fellows were making a difference in environmental science, as well as making history.

The summer began with each Fellow outlining a project that was agreed upon by the EPA office in which they served. The summer ended with the nine Fellows each presenting an hour-long seminar to EPA staff based on their project, and submitting full research papers to AAAS about these projects. These efforts were substantial, and designed to make a difference through their serious contributions of environmental scientific and technical information.

How they made a difference is captured in these papers. Some of the Fellows undertook research that involved reviewing known data, but compiled it in a way that made it available to the Agency in a new format. Others did not have existing data to work with and initiated data collection to pursue their research. Many Fellows included concrete recommendations for EPA to implement.

How they made history was simply by being the class of 1997. This class of summer Fellows will be the last at EPA, with next year's Environmental Fellows being selected for a one-year program at the Agency, for 1998-99. Although the decision to convert the summer program to a yearlong program at EPA was not made until the 1997 Fellows had finished their 10 weeks, that decision guarantees them a place in the history of the Agency and AAAS. Further information about this change will be announced early in 1998.

In the 17 years of the summer program, over 150 scientists and engineers have been placed at EPA. The program has provided an opportunity to learn firsthand how scientific and technological information is used in EPA's regulatory decision-making and environmental policymaking, while the Fellows make contributions that supplement the work of the permanent professional staff. The program has always been held in high regard. AAAS has required a national recruitment and a peer-reviewed selection process.

There are many people who contributed to the 1997 program. Special recognition is due Karen Morehouse who, as EPA's project officer, worked with the Fellows to find appropriate placements within the Agency, and was available for the Fellows when they bumped into the system or needed an additional professional perspective. AAAS appreciates the support of her office, the National Center for Environmental Research and Quality Assurance within the Office of Research and Development, which made this program possible.

Thanks are also due to those who helped produce this volume, starting with the Fellows themselves, who provided the summaries of their research papers for publication. Ted Smith, a program assistant on the AAAS fellowship staff, carefully formatted the text and graphics; Celia McEnaney, senior program associate, capably coordinated the editing, proofing, design, and printing of the book.

Full copies of the reports summarized in this book and information about the seven 1998-99 AAAS science policy fellowship programs are available from the AAAS Directorate for Science and Policy Programs at 202/326-6700, or by e-mail to science_policy@aaas.org.

Claudia J. Sturges
Manager
AAAS Science and Engineering Fellowship Programs
December 1997

1 Development of a Phytoremediation Handbook: Considerations for Enhancing Microbial Degradation in the Rhizosphere

TODD A. ANDERSON

In 1992, the U. S. Environmental Protection Agency (EPA) established the Remediation Technologies Development Forum (RTDF) after industry representatives expressed interest in working with EPA to solve hazardous waste remediation problems. RTDF consists of scientists and engineers from industry, government agencies, and academia interested in researching, developing, testing, and evaluating more cost-effective treatment technologies. An innovative treatment technology currently of interest to RTDF uses vegetation to enhance remediation of con-taminated sites. This technology has been termed “phytoremediation.” The principal advantage of phytoremediation is the cost savings compared to other remediation technologies (Cunningham *et al.*, 1997). Phytoremediation methods currently being tested include (1) “phytoextraction” and “rhizofiltration” for metals-contaminated sites and (2) “phytodegradation,” “phytovolatilization,” and “rhizosphere degradation” for organic contaminants (USEPA, 1996). As part of its efforts, RTDF is developing a handbook on phytoremediation to serve as a resource for industry and regulators for making informed decisions about when phytoremediation may be appropriate as well as give some guidelines for implementation.

TODD A. ANDERSON is currently with the Institute of Environmental and Human Health at Texas Tech University in Lubbock, Texas. His expertise is in environmental fate and environmental toxicology. He holds a Ph.D. in environmental toxicology from the University of Tennessee at Knoxville. During his AAAS fellowship, he worked at the Technology Innovation Office in the Office of Solid Waste and Emergency Response.

One of the areas of phytoremediation technology involves "rhizosphere degradation," or the use of vegetation to enhance microbial degradation of organic contaminants in the root zone or rhizosphere (reviewed by Anderson *et al.*, 1993; Shimp *et al.*, 1993). This technology takes place in soil surrounding plant roots (the rhizosphere) and is highly dependent on the increased density, diversity, and activity of microorganisms produced by the "rhizosphere effect" (Curl and Truelove, 1986). Thus, selection of the appropriate plant species can be critical to the success of this technology. Despite the interest in phytoremediation technology, the handbook essentially represents only a first attempt at providing information and guidance related to plant selection.

Mechanisms of Enhanced Degradation in the Rhizosphere

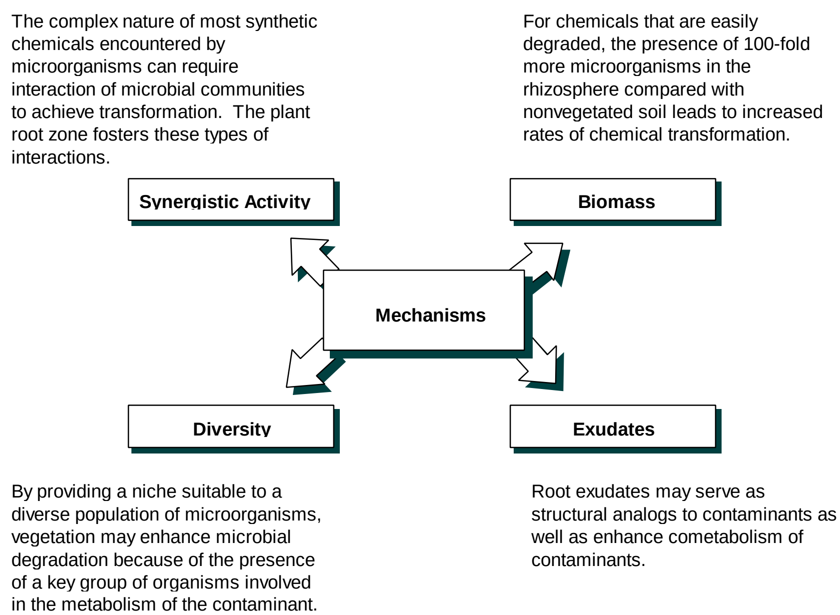
There are several potential mechanisms for the enhanced microbial degradation observed for some organic contaminants in the root zone (Figure 1). A better understanding of these mechanisms and the interaction between plants, microorganisms, and contaminants may be useful in extending the application of phytoremediation to additional contaminated sites (Crowley *et al.*, 1997).

Increased Microbial Biomass

For chemicals that are easily degraded, an increase in the numbers of microorganisms in the rhizosphere is likely the reason behind the enhanced degradation. In this simple scenario, the presence of 100-fold more microorganisms in rhizosphere soil compared with nonvegetated soil translates into an increase in the degradation rate for the contaminant. A good example of this mechanism is the recent research with vegetation and the primary component of de-icing fluid, ethylene glycol (EG) (Rice *et al.*, 1997). Based on this study and others (Sandmann and Loos, 1984), the positive impact that vegetation could have through simply increasing microbial biomass would appear to be limited to sites with readily degradable contaminants.

Increased or Synergistic Microbial Activity
The complex nature of most synthetic chemicals that are encountered by microorganisms can require the interaction of microbial communities at the molecular, physiological, and ecological levels to achieve bio-chemical transformation (Lappin *et al.*, 1985). The plant root zone fosters these types of interactions. Collectively, the microbial community may provide the spectrum of degradative enzymes, each of which may be required for mineralization but may not all be present in a microbial strain.

Figure 1. Summary of potential mechanisms for the enhanced microbial degradation of organic contaminants in the root zone or rhizosphere.



Increased Microbial Diversity
By providing a niche suitable to a diverse population of microorganisms, vegetation may enhance microbial degradation because of the presence of a key group of organisms (Liu *et al.*, 1991). Generally, the rhizosphere is colonized by a predominantly Gram-negative bacterial community. Interestingly, Gram-negative bacteria appear to have some important metabolic capabilities for degrading xenobiotic chemicals not found in Gram-positive microorganisms. Glutathione-S-transferase (an enzyme responsible for conjugation of xenobiotics in mammals, plants, and microorganisms) is particularly active among Gram-negative bacteria, including the genera *Pseudomonas* and *Enterobacter* (Zablotowicz *et al.*, 1994).

Root Exudates as Structural Analogs
Often, the presence of structural analogs to the chemical of interest will enhance microbial degradation. Such was the case with polychlorinated biphenyl (PCB) degradation, where biphenyl was used to enhance the activity of PCB-degrading bacteria (Bedard *et al.*, 1987). Donnelly and co-workers (1994) have explored this idea further by using plants to provide the structural analog(s) in the form of root exudates. These studies revealed that certain phenolic compounds in root exudates could support growth of PCB-degrading bacteria while also maintaining their ability to degrade various PCB congeners. Additional studies revealed that, among others, red mulberry (*Morus rubra*) was capable of producing large amounts of root phenolics (Fletcher and Hegde, 1995).

Cometabolism
The presence of exudates diverse in nutritional quality makes the rhizosphere a good place for cometabolism of chemical contaminants (Haby and Crowley, 1996). Early studies on organophosphate insecticides were useful in identifying this mechanism (Hsu and Bartha, 1979).

Phytoremediation of Organic Contaminants in the Rhizosphere

Site Selection Criteria

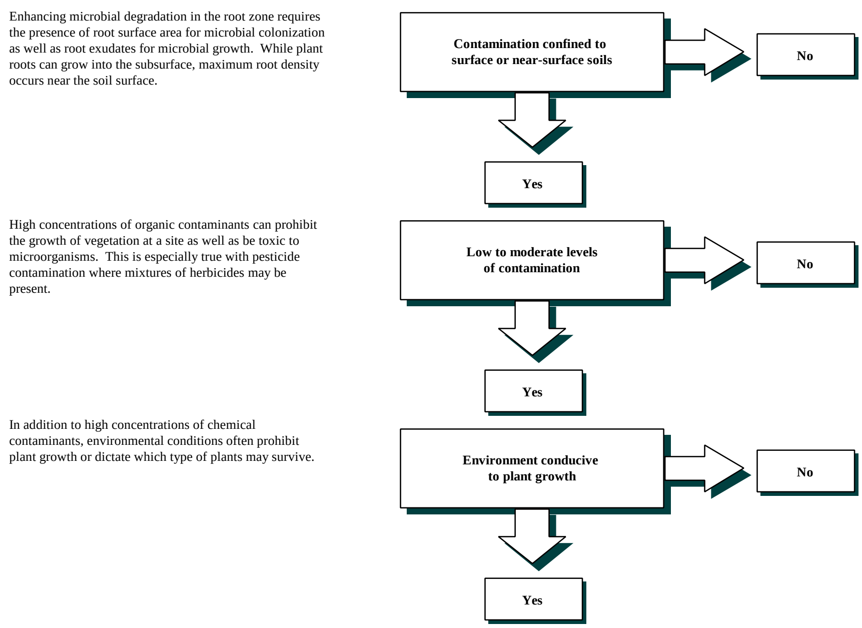
Several criteria should be considered before phytoremediation of organic contaminants in the rhizosphere is selected as an appropriate treatment option for a particular contaminated site (Figure 2). These criteria are related to the chemical and environmental characteristics important to microbial degradation in general as well as the characteristics (limitations) of the vegetation specifically.

1. Contamination Confined to Surface or Near-Surface Soil: Enhancing microbial degradation in the root zone requires the presence of root surface area for microbial colonization as well as root exudates for microbial growth. While plant roots can grow into the subsurface, maximum root density occurs near the soil surface. Thus, the use of vegetation to enhance microbial degradation will be limited to surficial soils.

2. Low to Moderate Levels of Contamination: High concentrations of organic contaminants can prohibit the growth of vegetation at a site, as well as be toxic to microorganisms. This is especially true with pesticide contamination, where mixtures of herbicides can be present at concentrations several-fold above the typical field application rate.

3. Environment Conducive to Plant Growth: In addition to high concentrations of chemical contaminants, environmental conditions often prohibit plant growth. While it is true that plants grown on contaminated sites to enhance microbial degradation are not typically grown for yield, overall plant health is important to phytoremediation.

Figure 2. Decision path for initially determining if the use of vegetation to enhance microbial degradation of organic contaminants is appropriate.



Plant Selection Criteria

Once phytoremediation has been chosen as an appropriate technology, plant selection becomes critical to success. There is a growing literature base on microbial degradation in the rhizosphere to draw upon when selecting appropriate plant species (see reviews by Anderson *et al.*, 1993; Shimp *et al.*, 1993; Schnoor *et al.*, 1995).

1. General Considerations: A good starting point for selection of appropriate plant species is to use vegetation naturally occurring at the site. Plants present at a site are able to grow in the area and survive the contaminated environment. At sites with petroleum contamination, where the soils are likely to be nitrogen-limited, leguminous plants may be beneficial in increasing microbial degradation by providing nitrogen to the soil (Gudin and Syratt, 1975).

Vegetation in these systems may also aid in soil aeration. With easily degraded materials, the selection of appropriate plant species is not as critical. Simply providing root surface area and exudates should encourage large numbers of microorganisms and will likely increase chemical degradation.

2. Type of Contaminant: There are several examples of studies that have identified plant species useful for enhancing microbial degradation of different classes of common contaminants (Figure 3).

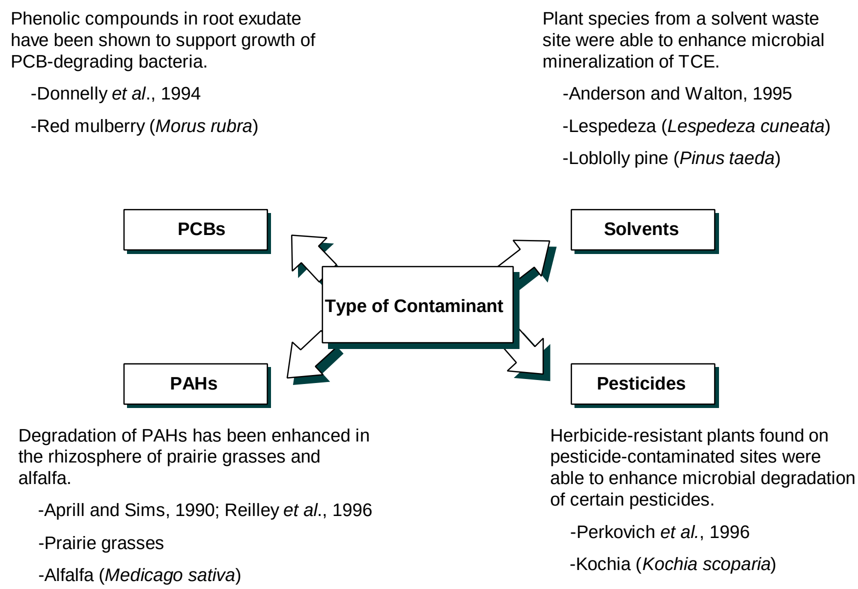
Phenolic compounds in root exudates have been shown to support growth of polychlorinated biphenyl-degrading bacteria and serve as structural analogs for PCB degradation (Donnelly *et al.*, 1994). Based on these studies, red mulberry (*Morus rubra*) appears to be a good candidate for enhancing microbial degradation of PCBs. In addition, Epuri and Sorensen (1997) reported increased mineralization and decreased extractability of hexachlorobiphenyl in soils planted with tall fescue (*Festuca arundinacea*), although total mineralization was very slight (less than 1 percent).

Anderson and Walton (1995) observed differences in microbial degradation of trichloroethylene (TCE) in the rhizospheres of five plant species. In whole-plant studies, the mineralization of ^{14}C-TCE was enhanced in three of the species tested (*Pinus taeda*, *Lespedeza cuneata*, and *Glycine max*), although only two (*P. taeda* and *L. cuneata*) were indigenous to the contaminated site. These results suggest that *L. cuneata*, loblolly pine, or soybean may be useful for enhancing microbial degradation in surface soil.

Aprill and Sims (1990) evaluated the persistence of four polycyclic aromatic hydrocarbons (PAHs)–benz[a]anthracene, chrysene, benzo[a]pyrene, and dibenz[a,h]anthracene in the root zone of a mixture of eight prairie grasses in soil- column studies. Residue analysis of the soil columns revealed that PAH disappearance was consistently greater in the vegetated columns than in the unvegetated controls.

In greenhouse studies, PAH degradation has also been shown to be enhanced by fescue, sudangrass, switchgrass, and alfalfa (Reilley *et al.*, 1996).

Figure 3. Examples of studies that have identified plant species useful for enhancing microbial degradation of different classes of contaminants.



Rhizosphere soils from several plant species were tested for their ability to mineralize two common pesticides, atrazine and metolachlor, at concentrations typical of point-source contamination (Anderson and Coats, 1995). Several rhizosphere soils tested positive for ^{14}C-atrazine mineralization including kochia (*Kochia scoparia*), lambsquarters (*Chenopodium berlandieri*), foxtail barley (*Hordeum jubatum*), witchgrass (*Panicum capillare*), catnip (*Nepeta cataria*), and musk thistle (*Carduus nutans*). Rhizosphere soils from kochia mineralized more than 60 percent of the added atrazine after 30 days (Perkovich *et al.*, 1996).

3. Other Selection Criteria: While selection of plant species based on contaminant(s) present and previous studies should be the primary criteria, other criteria should be considered. These criteria are related to potential land-use issues, including maintenance of vegetation, landscape considerations, potential additional uses of vegetation, and wildlife habitat/exposure.

Conclusions

Several criteria related to contaminants and their location within the matrix should be considered before phytoremediation is selected as an appropriate treatment option for a particular contaminated site. Selection of the appropriate plant species is the critical step for the success of this technology. A better understanding of the mechanisms involved can be useful in the plant selection process. In the absence of greenhouse treatability studies, plant selection for a specific compound should also consider chemical and environmental characteristics important to microbial degradation and draw upon the growing literature base.

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Address correspondence to:
TODD A. ANDERSON

The Institute of Environmental and Human Health
Texas Tech University
452 South Gilbert Avenue
Lubbock, TX 79416

2 Characterizing Risk at Metal-Finishing Facilities

DENNIS J. BROWN

Facility-based risk characterization for workers and the surrounding communities is a high-priority issue for stakeholders in the Environmental Protection Agency's (EPA's) Common Sense Initiative (CSI) metal-finishing sector (USEPA, 1997a). Platers, environmental groups, community groups, labor, and regulators all need and want to know what emissions are coming out and in what amounts from metal-finishing operations. They also want to know what health risks those emissions create for workers and the surrounding communities. The scientific process of risk assessment may provide a valuable tool to these stakeholders because it can be used to better understand and evaluate the human health effects associated with chemicals emitted by metal-finishing facilities.

Risk assessment estimates the chance that unwanted health effects will occur as a result of exposure to a chemical, biological, or physical agent. Human health risk assessment begins to quantify the unwanted effects by identifying the nature of the potential injury (hazard identification) and the populations that are at risk (exposure assessment). Then the relationship between a given exposure and the potential injury (dose-response assessment) is measured. By combining these three pieces of information, the probability that harm will occur (risk characterization) is predicted (NRC, 1983; NRC 1994). The outcome of the risk assessment process is one of several inputs considered by those who manage risks (Figure 1).

DENNIS J. BROWN is currently a principal biologist for Parsons Engineering Science, Inc. in Oakland, California. His expertise is in ecological and human health risk assessment. He holds a Ph.D. in biology from the University of California at Santa Cruz. During his AAAS fellowship, he worked in the U.S. EPA National Center for Environmental Assessment and the U.S. EPA National Center for Environmental Research and Quality Assurance.

This study identifies problem formulation as an important step in the risk assessment/risk management paradigm. The problem formulation step is included to ensure that the health information needs of the different metal-finishing sector stakeholders are identified early in the process and that the risk assessment step is focused on those issues of greatest concern to stakeholders. The problem formulation and/or risk assessment steps may be iterated following communication of the results to stakeholders, or they may lead directly to a risk management decision.

To illustrate the risk assessment step a facility conceptual model is developed for a chromium electroplating facility. The model identifies the potential pathways by which workers and surrounding communities may be exposed to emissions from a metal-finishing facility. Available toxicity information and exposure data, incorporated into a simple computer-based spreadsheet format, are then used to estimate the probability of unwanted health effects from emissions to worker and residential populations. An example is given using emissions from a chromium electroplating facility.

Uncertainties associated with toxicity information and exposure scenarios will present challenges for providing simple (but not simplistic) methods of risk assessment that can be applied by facility operators, community groups, and other stakeholders. It is not only possible but desirable to carry out this type of risk characterization for a variety of exposure scenarios.

Common Sense Initiative and the Metal-finishing Sector

CSI is an attempt by EPA to take a new approach to creating policies and environmental management solutions for American industries (Browner, 1994).

EPA has selected a representative cross section of American industries to test and refine CSI concepts and to create environmental solutions that can operate across industries and could be applied to other industry sectors (USEPA, 1994). Stakeholders in the CSI metal-finishing sector include the American Electroplaters and Surface Finishers Society (AESF), the Natural Resources Defense Council (NRDC), the AFL-CIO, the Barrio Planners of Los Angeles, the Water Environment Federation, and the Association of Municipal Sewerage Agencies. They have identified a set of National Performance Goals for the sector. These goals include three facility-based performance goals:

- Reduction in hazardous emissions and exposures
- Increased economic payback and decreased costs
- Improved resource utilization.

The National Performance Goals also include two sector-wide performance goals:

- Industry-wide achievement of the facility-based goals
- Industry-wide compliance with environmental performance requirements (USEPA, 1997b).

Stakeholders in the CSI metal-finishing sector have also produced a National Metal-Finishing Research and Development Plan, which identifies eight priority research needs (USEPA, 1997a). The highest priority is to develop and apply simple methods to characterize the emissions from chromium electroplating operations and to use the output from these methods to characterize the health risk to workers, surrounding communities, and the environment.

The stakeholders desire a "customer-oriented" product that will address one of the most significant environmental needs of the metal-finishing industry and that will be accessible to and easily understood by the operators of typical metal-finishing facilities (many of which are small job shops) as well as regulatory staffs and the public.

By explaining the steps performed and the data needed to conduct a risk assessment, this paper tries to assist stakeholders in the CSI metal-finishing sector to better understand the risk assessment process and the questions that can be answered by the process.

Assessing Risk at a Chromium Electroplating Facility

Individuals in two potentially exposed populations, workers and nearby residents, are considered in the example risk assessment for a chromium electroplating facility (Figure 2). For simplicity, the chemical of concern at the facility is limited to hexavalent chromium, a chemical classified by EPA as a known human carcinogen by inhalation. Toxicity values are obtained from available toxicological databases. Individuals of both populations are assumed to be exposed to hexavalent chromium via inhalation, dermal contact, and/or ingestion of soil or water contaminated with chromium. Because the two populations would be spatially separated, each is potentially exposed via a unique set of exposure pathways (an exposure pathway describes how the chemical is transported from the point of release to the point of exposure) and to differing concentrations in soil, water, and/or air. Other factors that affect exposure include the duration and frequency of exposure for each population and the physiological characteristics of individuals within the populations, such as breathing rate, water or soil ingestion rate, and body weight.

The exposure information is used to develop equations that quantify the amount of hexavalent chromium to which individuals may be exposed on a regular basis (i.e., the average daily dose). This information is combined with the toxicity information for the carcinogenic effects of hexavalent chromium to estimate a lifetime excess cancer risk from exposure to hexavalent chromium for four different exposure scenarios, two for workers and two for residents (Figure 3).

Two different sets of chemical concentrations in environmental media were selected for the worker and residential scenarios to reflect the difference in the internal and external environments at the facility. In addition, within each population, exposure characteristics such as breathing rate, exposure duration and frequency, and food and water uptake were varied to derive both "upper bound" (Scenario I for each population) and "average" (Scenario II for each population) estimates of risk. A computer-based spreadsheet that allows exposure values to be varied by the user was employed. A facility operator, for example, could insert facility-specific or population-specific information (when such information is available) to derive facility-specific estimates of risk.

Conclusions

Facility-based risk characterization for workers and the surrounding communities is a high priority for stakeholders in the CSI metal-finishing sector. The general methodology for carrying out risk assessments to characterize risk for metal-finishing workers and neighbors is known. It was possible to carry out such calculations for a number of scenarios using a simple computer-based spreadsheet. This approach could be applied to other industrial processes. Such risk characterizations directly assist stakeholders in making risk management decisions.

The methodology has limitations associated with toxicity information (measures of effect) for chemicals used in the metal-finishing sector and for appropriate exposure scenarios (measures of exposure), such as environmental concentrations of chemicals and activity patterns of potentially exposed individuals. Reducing the uncertainties associated with toxicity information and exposure scenarios would require research in these areas.

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Address correspondence to:

DENNIS J. BROWN
Parsons Engineering Science, Inc.
2101 Webster Street, Suite 700
Oakland, CA 94612

3 The Use of Environmental Information by Place-Based Environmental Groups

SUSAN CHARNLEY

Governments around the world use three main methods to control pollution and to protect human health and the environment: regulatory approaches, economic instruments, and information strategies. During its first 25 years, the U. S. Environmental Protection Agency (EPA) relied primarily on the regulatory approach. More recently, EPA has turned to information strategies as an important supplement to the regulatory approach. One of EPA's 12 environmental goals for the United States is to empower people with information and education and to expand their right to know. EPA believes that environmental information is a strategic resource that can empower Americans to make better environmental decisions and policies, to improve their environmental behavior, and to find creative new ways of promoting environmental protection. Toward this end, EPA is currently spending $400 million annually to develop and better manage its environmental information resources, and to make them more accessible to the public.

Information strategies are considered to be the new wave in pollution control efforts. While nobody doubts that environmental information is good, to date surprisingly little research has been done to examine exactly how it leads to improvements in environmental quality. A better understanding of how information strategies work can help shape the nature of these strategies in the future, and make them more effective. In addition, demonstrating that information strategies help control pollution and protect human health and the environment in the United States will make it possible to validate them as a viable alternative to the command and control regulatory approach.

SUSAN CHARNLEY is currently with the TetraTech Corporation in Calistoga, CA. Her expertise is in the social and cultural dimensions of natural resource use and management. She holds a Ph.D. in Anthropology from Stanford University. During her AAAS fellowship, she worked in the EPA's Office of Information Resources Management Planning Division.

This will also justify EPA's expenditures on environmental information, thereby fulfilling the requirements of the Government Performance and Results Act and the Information Technology Management Reform Act.

The Study

During the summer of 1997 I conducted a research project on the use of environmental information by place-based environmental groups. My research aimed to provide insight into the following questions:

1) How do information strategies work?
2) How are people actually using existing environmental information?
3) What are the mechanisms by which environmental information translates into better environmental quality and human health?
4) Is it possible to demonstrate the connections between environmental information and improvements in environmental quality, and to measure those improvements?
5) Who is positioned to make the most effective use of environmental information?

Clearly these are large questions that cannot be answered in a short time period. This project was designed to be a first step in what will, I hope, become a longer-term research endeavor.

My summer study focused on one specific user-group of environmental information: local groups organized around place-based environmental protection efforts. I chose this population for two reasons. First, these groups want to be empowered to improve environmental quality at the local level, and can potentially have a significant impact in this regard. Second, EPA states in its strategic plan that it will emphasize community-based solutions to environmental protection. Clearly, local environmental groups are one important target audience for environmental information.

I interviewed leading representatives of 23 groups engaged in place-based environmental protection in Maryland, Virginia, Washington, D.C., and West Virginia.

These groups can be characterized as follows: eight watershed groups, six community groups, three groups working on regional or statewide issues, three land trusts, two sustainability groups, and one tribe. I asked group representatives how they use environmental information to mobilize support for their causes and achieve their objectives. My focus was on three specific types of environmental information: information on environmental status, quality, and trends; community right-to-know information; and educational information.

Findings

My first set of questions centered on why interviewees had joined or founded their local environmental group. I wondered if there were key pieces of environmental information that motivated people to become environmental activists. I found that lower-income people and African Americans generally became environmental activists due to human health concerns relating to facilities in their communities. In contrast, mid- to upper-income Euroamericans generally became environmental activists out of a feeling of care for and connection to the natural environment in the places where they live or they use for recreational purposes. This feeling led to a desire to protect those places. Thus environmental information was not a key variable in motivating people to become activists. However, once people became involved in place-based environmental protection efforts, they became seekers and consumers of environmental information.

I found that local environmental groups use information on environmental status, quality, and trends in the following ways:

1) to pinpoint source areas of contamination so they can be addressed;
2) to monitor and informally regulate polluters;
3) to develop policies and promote legislation to protect environmental quality;
4) to identify where to implement restoration projects and to get support for those projects;
5) to target areas for conservation;

6) to address litter problems;
7) to develop environmental indicators; and
8) to assist in growth management and minimize the undesirable impacts of development in sensitive habitats.

Virtually all of the information on environmental status, quality, and trends used by groups in my sample pertains to water and land-based resources; they were not using environmental information on air quality. The groups in my sample obtain very little information on environmental status, quality, and trends from EPA. Local environmental groups are concerned about local environmental problems and need local-level environmental information. They find that EPA data are not fine-grained enough to be useful to them; thus they get what they can from other sources. This raises an important policy question: to what extent does EPA want to be a producer vs. a provider of environmental information? The partnership model can work well in this regard. The Chesapeake Bay Program—a federal-state-local partnership in which EPA represents federal government agencies—produces a lot of environmental information specific to the Chesapeake Bay region. Environmental groups working within the Chesapeake Bay watershed use this information and find it extremely helpful.

The groups in my sample use community right-to-know information in the following ways:

1) to identify who is discharging what, and to target polluters and the issues to discuss with them;
2) to identify nonpolluters and recognize them with good publicity to provide incentive for others to reduce their toxic releases;
3) to inform citizens about pollution sources and levels in their communities, and to thereby pressure local manufacturers to reduce toxic releases;
4) to support better air and water legislation and programs;
5) to develop environmental indicators; and
6) to pressure polluters who violate their permits to clean up.

In comparison with the other two types of environmental information, community right-to-know information is used the least by the groups I interviewed. Most groups make little use of community right-to-know information because they do not focus on toxics issues, they have a paucity of regulated facilities in their areas of concern, or pollution from sources other than regulated facilities is their primary problem.

Several groups stated that community right-to-know information would be more useful if it were accompanied by better risk information. But the groups believe in making this information available, and some have lobbied hard to promote and protect community right-to-know legislation in their States.

Educational environmental information used by groups in my sample aims to inform citizens about local environmental problems, why they matter, how citizens' behavior contributes to the problem, and what citizens can do to reduce the problem. Environmental groups must produce educational information that is understandable and meaningful to the specific populations they are trying to reach. The primary goal of the information is to encourage citizens to change their behavior and act in ways that are more environmentally friendly. A secondary goal is to encourage people to become more active in environmental issues. It would require a separate study to assess whether or not educational information is making a difference in this regard.

The groups in my sample used EPA's educational information more than the other two types of environmental information made available by EPA. Some distribute EPA informational brochures; others read these and draw on them when producing their own educational information. One policy question regarding educational information that arises here is: should EPA try to meet the educational information needs of diverse populations, or should it provide support to other groups whose mission is to do this?

Conclusions

Place-based environmental groups want environmental information and they use it in many influential ways. While they disagree about what role EPA should play as a producer of environmental information, they concur that EPA should be a provider of environmental information. Several expressed a desire for EPA to provide an information clearinghouse that would help them identify what environmental information is available and where to get it in a timely manner.

While environmental information is important, groups can make effective use of it only if they have the resources to gain access to it, the knowledge and skills to use it, and the power to have an impact with it. Environmental information is only one of many variables that influence environmental decision making. Public pressure and political and economic variables also play important roles in determining the outcome of environmental decision making processes. Nevertheless, without environmental information, environmentally sound policy decisions, programs, legislation, and behavior are much less likely to occur.

Address correspondence to:

SUSAN CHARNLEY
Tetra Tech, Inc.
2436 Foothill Boulevard
Suite J
Calistoga, CA 9451

4 Project Selection for EPA's Sustainable Development Challenge Grant Program: A Multi-Criteria Analysis

ALEXANDER E. FARRELL

The Environmental Protection Agency's (EPA's) 1996 Sustainable Development Challenge Grant (SDCG) program is evaluated through a program review and by a Multi-Criteria Analysis (MCA) that elicits expert opinion across and outside the Agency. The principal focus is placed on selecting the portfolio of winning projects.

From the program review, EPA's efforts in 1996 are found to be generally sound, although improvements are needed as the program scales up from a pilot level. In addition, the outcome of the 1996 selection process seems to be robust. Nearly all of the experts stated that the concept of sustainability is central to the mission and activities of EPA, and many other parts of the U.S. government as well, despite being difficult to define and implement. Fortunately, the SDCG program significantly increased EPA's capacity to implement sustainability, and appeared to do the same for the applicants. MCA highlighted significant commonalities among the experts on how the concept of sustainability should be applied in this case, but identified many differences as well.

ALEXANDER E. FARRELL is currently a research fellow at the Kennedy School of Government working on the Global Environmental Assessment Project. His expertise is in nuclear and systems engineering, multi-criteria decision analysis, advanced pollution regulation, sustainable development, and energy policy. He holds a Ph.D. in Energy management and Policy from the University of Pennsylvania. During his AAAS fellowship, he worked in the Office of Air and Radiation.

In general, the experts who participated in this research felt that the MCA procedure helped them to think more clearly about sustainability and to better make decisions that reflected the concept. A few dominant criteria emerged from MCA that may be useful in designing similar efforts in the future. Several significant policy implications also emerge from this research and are presented.

This paper summarizes an analysis of the Environmental Protection Agency's (EPA's) 1996 Sustainable Development Challenge Grant (SDCG) pilot program. More broadly, this research touches on theory and methods that can be used to help apply meaningfully the concept of sustainability in decision making.

Sustainability and the Challenge Grant Program

The concept of sustainability is gaining acceptance at all levels of government and society, yet its implementation poses a serious challenge to decision makers because, although sustainability is a widely used term, it is hardly an agreed-upon concept. The most common definition of sustainability is that the needs of the present generation are met without compromising the ability of future generations to meet their own needs. However, this definition, like most, cannot be readily used in practical applications to make decisions.

Aggravating this problem is the fact that sustainability is a complex and controversial idea that affects virtually all segments of society, involves very long time horizons and very large scales, and may require deep changes in current practices and trends in order to achieve. Thus it is not surprising to find confusion about how to define sustainability, let alone what kinds of projects, technologies, or policies will lead us there.

Although there are many definitions of sustainability, it is helpful to put them into two general categories. In the first category are definitions that are essentially about competing objectives. These objectives are usually broken into three types—ecological, social, and economic—often represented with a triangle or as a three-legged stool.

An important variant of the competing-objectives category is the integrated-objectives view, which holds that sustainability exists only when institutional arrangements, technologies, and decisions line up to mutually support all three types of objectives so that they are achieved simultaneously without trade-offs.

The second category contains definitions of sustainability that are called biogeophysical, where the key idea is that some environmental assets provide goods or services that humankind cannot do without, and that we do not know how to replace, reproduce, or otherwise substitute for. These ideas point toward the notion of a maximum supply of ecological goods and services that the biosphere can provide over the long run. This maximum is often called the carrying capacity of the biosphere, and it implies the existence of biogeophysical limits, which must always be respected and critical environmental features, which must always be preserved. Importantly, however, carrying capacity is endogenous with respect to technology and tastes, i.e., while there may be limits to the flows of goods and services the biosphere can provide, technological innovation (especially efficiency improvements) and changes in consumption patterns mean that there is no direct link between these limits and human population, consumption, and well-being. This causes some controversy over which issues truly invoke biogeophysical sustainability.

The reason for making this distinction is that these two categories of definitions have very different implications. The biogeophysical category allows for very strong policy prescriptions, so the term "ecological imperative" is sometimes used to advance policies to achieve biogeophysical sustainability. By contrast, the competing-objectives category is a less significant departure from existing policy debates. Additionally, the range of issues to which biogeophysical sustainability applies is likely very small, which technology may be able to reduce over time. By contrast, in either the competing- or integrated-objectives view, it seems that virtually any environmental protection issue is fair game (and possibly many other policy questions as well).

Thus a view of sustainability about competing (or integrated) objectives applies to more decisions and is broader, but weaker than, biogeophysical sustainability.

SDCG is one of several programs in the federal government related to sustainability, and is designed to "encourage people, organizations, business, and government to work together in their communities to improve their environment while maintaining a healthy economy and sense of community well-being." The SDCG program provides relatively small grants on a competitive basis to community groups across the country. This research examined only the 1996 SDCG pilot program, which was funded at $500,000 and announced in the *Federal Register* on July 1, 1996 (pp. 33,913-33,917). Approximately 620 proposals were received, of which about 300 were subjected to a two-stage review process that involved dozens of EPA staff people from both the Washington, D.C. headquarters and the 10 regional offices. Eventually, 10 projects were selected for funding.

Research Objectives and Method

This research is aimed primarily at investigating methods by which the concept of sustainability can be used in decision making and what the concept means for EPA. More specifically, the objectives of this research are to document and analyze the decision making process used by EPA to select the portfolio of winning SDCG proposals, and to elicit and synthesize expert opinion on how the process could be improved. Two research methods were used. The first was a literature review and a set of personal interviews conducted with participants involved in the 1996 SDCG program. The second was a series of "decision exercises" with experts on sustainability who were asked to choose the best portfolio of Sustainable Development Challenge Grant projects. The decision exercises were highly structured interviews that were used to elicit judgments. A Multi-Criteria Analysis (MCA) framework was developed for each interviewee, which could then be used as a basis of comparison among the experts. A total of 24 decision exercises were conducted with 36 individuals, across as well as outside EPA.

Results

Almost all of the people interviewed for this research believe sustainability should be a central goal for EPA (if not for the U.S. government). However, as an emerging issue, the concept is not yet reflected in the Agency's programs and policies. Importantly, there is a developing and complementary view in that the National Environmental Protection Act actually requires all federal agencies to implement sustainability in the course of their otherwise mandated activities.

The project selection process used in the 1996 SDCG program was generally sound. Some flaws were noted but these could be corrected in future programs (and many have been in the 1997 program). Importantly, the EPA staff who participated in the 1996 program recognized some of the more important problems as they developed, and they took corrective actions. The selection process was rather tortured and time-consuming, but this is to be expected during the first year.

The portfolio of 10 projects selected for funding in 1996 appears to be a robust set based on interviews with participants, i.e., there does not seem to be another set of 10 projects that could have been selected from among the initial pool that would be significantly better than the portfolio that was actually selected, although differences as to the merits of one or two projects might exist with any particular individual. All of the participants noted significant frustration that many good projects were not funded under the 1996 SDCG program due to the limited budget.

The capacity of the EPA staff involved with the SDCG program to understand and implement sustainability increased significantly by working on the program, and there is evidence that the same is true for the applicants. Although this capacity development is not an explicitly stated goal of the SDCG program, it is a crucial result. If sustainability is an important national goal, then it is vital that the Agency develop the capacity to use the concept in decision making across a broad array of choices, and to foster similar abilities around the country.

However, the program's current location in the EPA's Office of Air and Radiation and Office of Water may hamper this ability somewhat, and recent changes to the leadership of the program make it unclear how it will proceed in the future.

The SDCG program also functions somewhat as a research effort. Because there are so many potential decisions that the concept of sustainability could be applied to and because the concept is not completely agreed-upon, clear examples of sustainability are not routinely available. This is part of the challenge of implementation—a challenge that can be met, in part, through field research into what works best. In the spirit of the States as "laboratories of democracy," it is useful to think of the communities participating in the SDCG program as "research centers on sustainability." The experts who participated in the decision exercises generally felt that the MCA approach was useful in three ways: it improved their own thinking about sustainability (particularly as it could be applied to a specific decision problem), it would substantively improve actual project selection, and it could be used for communication and education.

The competing- or integrated-objectives view clearly dominated in the MCA process, although biogeophysical sustainability was sometimes noted. Over 350 individual criteria were defined during the decision exercises, and any comparison among them requires considerable judgment. After careful analysis, 64 standardized criteria were developed. Two types of criteria were specified—those that were strictly used as screens or thresholds and those that were to be traded off in evaluating proposals. Three key screening criteria were identified, and they appear in Table 1; ten criteria seemed to dominate the trade-off exercises and are included in Table 2.

It should be kept in mind that this is a somewhat subjective evaluation and much of the content of the decision exercises is lost in such a brief discussion.

Conclusions and Policy Recommendations

This research provides evidence that MCA can be useful in making decisions that advance sustainability. It also showed that the EPA's 1996 SDCG program was successful in selecting a robust set of projects to fund, although the selection process should be improved. It also highlighted the fact that a relatively modest grants program aimed at the community level cannot address some of the most pressing sustainability-related issues, which are governed by forces and institutional arrangements at higher levels. While it is too early to definitely evaluate the success of the program, there are initial indications that it has achieved its objectives and more. Most importantly, this research suggests that the concept of sustainability is a crucial issue for EPA (and possibly other branches of the U.S. government), although it is not clear if the Agency is ready to implement it at this time. Specific policy recommendations include:

- EPA leadership should consider incorporating the concept of sustainability as a central part of the Agency's mission and use it as a guide in all Agency decisions and actions.

- The SDCG program should continue to be improved; but it may be more effective if placed elsewhere within the Agency, perhaps as a joint national effort by the Office of Policy, Planning, and Evaluation and regional offices.

- The ability of the SDCG program to increase EPA's capacity to implement sustainability should be strengthened through a rigorous research program and by fostering inter-Office and headquarters-regional cooperation.

- The Administration should consider initiating similar programs in other federal agencies, or a cross-Agency program coordinated by an appropriate body, such as the President's Council on Sustainable Development.

- A wider review of the project selection criteria should be undertaken to improve the SDCG program. This could be accomplished by EPA alone or in conjunction with other federal agencies, or by the Science Advisory Board. In any case, all appropriate technical skills and disciplines should be brought to bear on the issue.

- The role of the SDCG program as a research and educational tool should be strengthened. In particular, the role of the applicant communities as laboratories for sustainability should be encouraged and capitalized on.

Sustainability is beyond the reach of any single government agency and will require coordinated action by many parts of the federal government and possibly new legislation as well, which highlights the importance of public support for the concept. However, the EPA's Sustainable Development Challenge Grant program is a valuable part of the federal government's current approach to sustainability and it should be strengthened and learned from.

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Address correspondence to:

ALEXANDER E. FARRELL
Research Fellow
Kennedy School of Government
BCSIA 79 JFK Street
Cambridge, MA 02138

5 Aerosols and Global Climate Change: Improving the EPA's Modeling Efforts

LAURIE S. GELLER

It has long been known that anthropogenically emitted greenhouse gases (GHGs) can interfere with the Earth's natural equilibrium between incoming solar radiation and outgoing infrared radiation. But only within the last few years have we come to recognize that aerosols (small particles suspended in the gaseous phase) can also cause significant radiative forcing (RF)[1]. Aerosol RF is much more difficult to quantify than GHG RF. Because aerosols are short-lived, their atmospheric concentrations and forcing effects are highly localized and transient. There are no comprehensive measurements of the global distribution or long-term trends for aerosols, which severely limits our ability to calculate their global effects.

The Atmospheric Stabilization Framework (ASF) is a model used by the Environmental Protection Agency to carry out detailed analyses of anthropogenic GHG emissions, and to determine a plausible range of scenarios for global climate change (EPA, 1990; Pepper, 1992). The goal of this work is to provide guidance for improving the treatment of aerosols in ASF. Four major types of tropospheric aerosols are included in this study—sulfates, black carbon, organics, and mineral dust.

LAURIE S. GELLER is currently a Program Officer with the National Research Council's Board on Atmospheric Sciences and Climate. Her expertise is in climate change and other global atmospheric processes. She holds a Ph.D. in Atmospheric Chemistry from the University of Colorado, Boulder. During her AAAS fellowship, she worked in the EPA's Atmospheric Pollution Prevention Division (OAR/OAP/APPD).

Aerosols—Scientific Background

<u>*sulfates*</u> The primary anthropogenic source of sulfates is oxidation of sulfur dioxide, which is emitted by fossil fuel combustion. Sulfates can affect climate in two ways: directly, through scattering incoming solar radiation, and indirectly, through modifying cloud formation; both effects lead to -RF. Estimates of the global-mean direct RF of anthropogenic sulfates fall in the range of -0.2 to -1.3 watts per meter squared. The indirect forcing effects are much more complicated and are far from quantitatively understood; most estimates of the global-mean effects fall within the range of -0.5 to -2.5 w/m^2. Recent studies have demonstrated that interactions between sulfates and other particles in the atmosphere can strongly affect the magnitude of sulfate RF.

<u>*black C*</u> Black C (or soot) comes from combustion of fossil fuels and biomass; the natural sources are thought to be negligible. Unlike the sulfate aerosols, black C absorbs solar radiation, leading to +RF. Haywood and Shine (1995) estimate a global-mean forcing of +0.1 w/m^2, but this considers only fossil fuel sources and likely underestimates the total forcing. Recently published global emission inventories of black C (Liousse *et al*., 1996; Cooke and Wilson, 1996) should greatly improve our ability to assess global RF effects.

<u>*organics*</u> Organic aerosols are both emitted directly and formed in the atmosphere from precursor gases. Anthropogenic sources include fossil fuel and biomass combustion and industrial emissions of hydrocarbons. Like the sulfates, organic aerosols can scatter incoming solar radiation (direct forcing) and can modify cloud properties (indirect forcing). Penner *et al*. (1994) estimate that the global-mean direct RF is around -0.5 w/m^2. The indirect RF could be even larger, but has not been estimated. Recent studies are finding that over many industrialized areas, organic aerosols account for a dominant fraction of the total aerosol mass and they are the largest contributor to light scattering and to cloud drop formation (Rivera-Carpio *et al*., 1995; Mazurek *et al*., 1997; Matsumoto *et al*.,1997).

mineral dust Mineral dust has traditionally been considered as purely natural, and thus has not been included in studies of climate change. However, Tegen and Fung (1995) argue that approximately 50 percent of the current total dust loading is due to the disruption of soils by human activities. Some of the major soil-disturbing activities are deforestation, overcultivation of agricultural land, overgrazing, road building, and mining. The RF effects of dust aerosol are very complicated; dust aerosol scatters solar radiation (-RF) and it can absorb both solar and IR radiation (+RF). The global-mean forcing is difficult to assess at this time, but on a local or regional level, mineral dust RF can be many times larger than that of sulfate and carbonaceous aerosols.

Developing Aerosol Emission Scenarios

Currently, only the sulfate aerosols are included in the ASF emission scenarios. Sulfate emission scenarios are based largely on anthropogenic emissions of SO_2, taking into account details such as the sulfur content of different fuels and the effects of protocols like the Clean Air Act. On the whole, anthropogenic sulfate emissions are well characterized by ASF. However, recommendations were made for updating the model's estimates for natural sulfate sources and for the rate of conversion of SO_2 to sulfate.

It should be relatively easy to develop emission scenarios for the black C and organic aerosols, because published global-source inventories provide emission factors for all of the major sources. Since these same sources also emit GHGs, they are already included in the ASF input data. The organic aerosol scenarios will be somewhat more complicated to develop, since one must consider the distinction between natural and anthropogenic sources and gas-to-particle conversion rates.

Mineral dust will be the most difficult type of aerosol for which to develop emission scenarios, as all of the sources are poorly understood. A global-source inventory given in Tegen and Fung (1994) provides a good starting point, but may not be detailed enough to provide all of the needed information.

New inputs into the ASF model will be needed to adequately quantify the soil degradation processes that lead to mineral dust emissions. Fortunately, a lot of this information is available, particularly from the United Nations' Food and Agricultural Organization and Environmental Programme.

Modeling Aerosol Radiative Forcing

Accurately modeling the RF effects of aerosols presents a significant challenge due to the large scientific uncertainties involved, the inherent limitations of the ASF atmospheric model, and the problems associated with relying on global-mean RF values.

At this point, the global-mean for direct sulfate RF is known to within about a factor of two; for direct RF by black C and organic aerosols, the uncertainty is about a factor of three. For mineral dust aerosols and for all indirect RF, the uncertainty is even larger, and is not even possible to quantify at this time (Penner *et al*., 1994). To reduce these uncertainties, we need to learn much more about the aerosols' sources and sinks, their size distribution and chemical composition, and their intrinsic radiative properties. While these large uncertainties greatly limit the precision with which forecasts can be made, they needn't preclude modeling efforts entirely, as long as the resulting error bars are explicitly reported.

The ASF atmospheric model was developed to provide a first-order assessment of global-mean climate changes, relative to pre-industrial times. It uses a simple 1-box model of the atmosphere, which considers only global-mean values. Thus the distribution of aerosol concentration and variations in environmental conditions cannot be accounted for. Any interactions between species must be proscribed in simple, empirically determined equations. Box models can usefully represent certain processes (such as the RF due to long-lived GHGs), but aerosols do not lend themselves well to such a simple model; their short-term variations, global distributions, and chemical interactions can all strongly influence the magnitude of RF, and thus these factors cannot be ignored without incurring some error (IPCC, 1995).

Like in many modeling studies, ASF reports global-mean RF estimates for the different GHGs and aerosols and a "net" global RF estimate for all of them together. However, these global-means can present a misleading picture about the relative importance of different forcing agents, and about the actual effects that may be felt at the Earth's surface. Lumping all of the GHG and aerosol effects together in a net global RF term just obscures the matter further, as this assumes that GHG warming and aerosol cooling will simply cancel each other out. But this is an incorrect assumption. While aerosol cooling may significantly dampen GHG warming over certain regions, the GHG and aerosol forcing effects have very different temporal and spatial characteristics, which preclude any simple cancellation on the global scale.

How then to proceed in the face of all these obstacles? Ideally, the answer would be to wait until the scientific uncertainties have diminished, and to use only sophisticated 3-D Global Climate Models to calculate RF. In the real world, however, EPA cannot afford such luxuries. Since international negotiations on a climate-change treaty are well underway, policy decisions on these matters need to be made quickly. Convenient, in-house tools such as ASF provide the only feasible means to examine a large number of emission scenarios and policy options within a reasonably short time frame. The following, then, are suggestions to help address some of these obstacles:

1) *Incorporate more spatial resolution into the model.*

Highly resolved maps of RF cannot be created, but it is feasible to calculate RF on a hemispheric level. Ideally, separate model "boxes" should also be used over continental and oceanic regions.

2) *Consider aerosol interactions and nonlinear forcing effects.*

Some of these relationships are too poorly quantified to represent in the ASF model as simple empirical relationships, however, they can at least be considered on a qualitative basis.

3) *Show error bars in the results and distinguish between GHG and aerosol uncertainties.*

> It is important to be upfront about the magnitude of uncertainties by putting error bars on all final results. It is recommended that results be shown both with and without aerosol effects, with the appropriate error bars for each case.

4) *Design the model with enough flexibility to incorporate new information as it becomes available.*

> Given the rapid progression of aerosol research, it is likely that our understanding of these issues will greatly improve over the course of the next few years. Having a separate aerosol "module" within the ASF will make it more convenient to frequently incorporate this new information.

Endnote

1: In general, positive RF tends to warm the Earth's surface, while negative RF tends to cool the Earth's surface. However, the relationship between RF and climate response is complex and poorly quantified. It is beyond the scope of this work to examine the issue of climate response, but it should be kept in mind as another layer of uncertainty atop those discussed here.

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Address correspondence to:

LAURIE S. GELLER
National Research Council
2102 Constitution Avenue NW, HA466
Washington, DC 20418

6 Estimation of Indoor Particulate Matter Emissions in Large Office Buildings: A Preliminary Evaluation of EPA's BASE Study Data

ADAM C. JOHNSTON

The summer of 1997 has seen the factious debate between members of Congress, the White House, and the U.S. Environmental Protection Agency (EPA) on the regulation of airborne particulate matter. The Clean Air Act, which serves as the statutory basis for these standards, has been interpreted to apply only to outdoor air and does not provide for any regulation of contaminants in indoor air. Individuals, however, spend as much as 90 percent of their time indoors (Robinson and Nelson, 1995; Jenkins *et al*., 1992). Although it is often thought that buildings provide some level of protection from elevated outdoor concentrations, indoor concentrations of particulate matter have been shown, in some cases, to be equivalent to or higher than outdoor concentrations in both homes and office buildings (Spengler *et al*., 1981; Turk *et al*. 1989; Wallace 1996), indicating that potentially significant sources of particulate matter may exist indoors.

In 1992, the Indoor Environments Division of EPA set out to characterize the baseline indoor air quality of large office buildings across the country. This ongoing study, the Building Assessment Survey and Evaluation (BASE) study, is currently in its fourth year of data collection, with anticipated completion in 1998.

ADAM C. JOHNSTON is currently with the Environ Corporation in Arlington, VA. His expertise is in environmental risk assessment and regulatory policy. He holds a M.S. in Environmental Science from the University of North Carolina at Chapel Hill. During his AAAS fellowship, he worked in the EPA's Office of Radiation and Indoor Air.

This comprehensive study is intended to collect data on numerous parameters that may be associated with indoor air quality, such as building age, construction, and design; ventilation design, operation, and measurement; indoor air quality measurements; potential indoor and ambient sources; and occupant perceptions of potential health effects.

This report presents an analysis of a preliminary data set of 26 buildings evaluated by EPA during the first 2 years of the BASE study. Specifically, a mass-balance model for particulate matter (PM_{10} and $PM_{2.5}$) movement into and out of large office buildings was developed and applied to estimate particulate matter emissions within the study buildings. Estimated emission rates were compared to identified sources within the BASE buildings.

Mass-Balance Modeling of Pollutant Infiltration into Buildings

The mass-balance approach used in the present analysis, as in any application, assumes that the mass entering the system must be equivalent to the mass leaving the system. In this case, the system is an area within a building, which is referred to as the "test space." A mathematical mass-balance model for estimating the particulate matter accumulation rate within a building's test space was developed, assuming the test space is at steady state. This approach considers the infiltration and exfiltration of particulate matter into and out of a building through both the ventilation system and the building envelope; the indoor removal of pollutants through either deposition onto surfaces or through filtration of recirculated indoor air; and indoor sources of emissions. In addition, potential differences in building behavior when the ventilation system is not operating (e.g., the pressure within the building may be reduced) were considered in model development, based on work by Weschler *et al*. (1983). Solving the mass-balance equation for the source emission rate, S, emissions of particulate matter in the BASE buildings may be calculated as follows:

$$S = -V\left(\begin{array}{l} f_{on}\left[n_{on}(1 - F_{OA})C_o - \dfrac{Q_{RA}F_{RA}}{V}C_i - n_{on}Csubo - \dfrac{R}{V} \right] \\ + f_{off}\left[n_{off}C_o - n_{off}C_i - \dfrac{R}{V} \right] \end{array} \right)$$

where: S = indoor source particulate matter emission rate, µg/hr

V = volume of the test space, m^3

v_{on} = air exchange rate of test space when ventilation system is on, hr^{-1}

v_{off} = air exchange rate of test space when ventilation system is off, hr^{-1}

f_{on} = fraction of time heating, ventilation, and air conditioning (HVAC) system operates, unitless

f_{off} = fraction of time HVAC system is not operating, unitless

C_i = indoor concentration of particulate matter, µg/m^3

C_o = outdoor concentration of particulate matter, µg/m^3

F_{OA} = combined filter efficiency applied to outdoor air, unitless

Q_{RA} = flow rate of return air through HVAC system to test space, m^3/hr

F_{RA} = combined filter efficiency applied to return air, unitless

R = indoor removal (deposition), µg/hr

Values for many of the parameters in the equation were available from data collected as part of the BASE study. For three parameters—air exchange rates, filter efficiencies, and the particulate matter removal rate—BASE data were not available; therefore, estimated values were developed.

Air Exchange Rate

Two methods for estimating the air exchange rate of the test spaces were used: (1) the rate of decay of carbon dioxide concentrations after occupants had left the building; and (2) the flow rate of outdoor air into the test space. In 9 of the 26 buildings evaluated in this analysis, discernible CO_2 curves were available from the continuous CO_2 monitoring data collected by EPA. A time period of CO_2 decay after individuals had left the building but before the ventilation system ceased operation was selected, and the air exchange rate was estimated from the slope of the CO_2 decay (Persily and Dols, 1990). For the buildings without identifiable CO_2 decay curves, the air exchange rate was estimated as the outdoor air flow rate into the test space divided by the test space volume. This method likely overestimates the actual air exchange rate of the test space; therefore, the values estimated using this method were decreased based on a comparison of values calculated using the two methods. For periods when the ventilation system was not operating, an air exchange rate of 0.1 hr^{-1} was estimated based on CO_2 decay data collected in the BASE buildings during periods when the ventilation system was not operating.

Filter Efficiency

The filtering efficiency of each filter was determined based on the filter rating, which was recorded by the BASE research team for each filter associated with the test space. Filter ratings do not necessarily represent the actual efficiency of a filter, which depends on particle size and air flow rate.

Based on data presented by Hanley *et al*. (1994) on the relationship between filter rating and efficiency over a range of particle sizes, representative filter efficiencies were estimated for outdoor air, supply air, and return-air filters.

Removal Rate

For a nonreactive pollutant, such as particulate matter, the rate of removal from indoor air, R, is estimated as the product of the deposition or settling velocity, the surface area available for deposition, and the indoor particulate matter concentration. The deposition velocity of a particle is affected by a variety of factors including gravitational settling, Brownian motion, and electrostatic forces, and it varies as a function of particle diameter.

Based on data identified in the scientific literature (Ligocki PM_2*et al*., 1990; Sinclair *et al*., 1988, 1992; Raunemaa *et al*., 1989; Thatcher and Layton, 1995), deposition velocities of 0.005 cm/s (0.18 m/hr) and 0.1 cm/s (3.6 m/hr) were used in the mass-balance model for $PM_{2.5}$ and PM_{10}, respectively. The surface area that is available for deposition is also a function of particle size. Large particles, such as PM_{10}, will tend to settle primarily on horizontal surfaces; therefore, the surface area available for deposition is approximately equivalent to the floor area of the test space. Fine particles, such as $PM_{2.5}$, however, may interact with surface coverings on walls and other non-horizontal surfaces (e.g., shelves, cubicles, computer terminals). Therefore, for$_{.5}$ it was assumed that the surface area available for deposition is five times greater than the floor area of the test space (Sinclair *et al*. 1992 ; Weschler 1991).

Estimated Particulate Matter Emission Rates in Office Buildings

Emission rates of PM_{10} and $PM_{2.5}$ in the BASE buildings were estimated using the equation above. The emission estimates expressed in terms of mass per unit time (µg/sec) released into the test space are shown graphically in Figure 1 for both $PM_{2.5}$ and PM_{10}.

The estimated average PM_{10} emission rate in the 26 BASE buildings was approximately 10 times greater than the estimated average $PM_{2.5}$ emission rate, which is not unexpected given that sources of fine particles (e.g., combustion and industrial processes) are not typically found in office environments. Cigarette smoking is a source of fine particles in air; however, only 3 of the 26 buildings allow smoking in the test spaces. Coarse particles may be generated by a wider variety of sources, many of which may be found in an office environment (e.g., vacuuming, dusting, resuspension of particles in carpets, paper handling). In addition, ventilation systems tend to coagulate fine particles into larger particles due to collisions in duct work.

Comparison of Estimated Emissions with Potential Indoor Sources

As part of the BASE study, EPA collected information on potential sources in the BASE buildings. One-way analysis of variance (ANOVA) tests were conducted to determine whether a significant difference exists among the mean indoor particulate emission rates in test spaces with and without the following potential emission sources: (1) smoking; (2) daily vacuuming; (3) daily dry mopping; (4) kitchenettes; and (5) computer rooms. These comparisons were conducted separately for PM_{10} and $PM_{2.5}$.

Significant differences between the mean emission rates of the groups identified above were not observed, with the exception of estimated PM_{10} emissions in test spaces with and without computer rooms and emissions of $PM_{2.5}$ in test spaces with and without smoking. It should be noted, however, that only three of the test spaces evaluated permitted smoking. Smoking is a source of fine particulate matter in air; therefore, potential impacts of this source on indoor $PM_{2.5}$ concentrations should continue to be evaluated when additional BASE building data are collected. The presence of a computer room as a potential source of PM_{10} is not intuitively obvious; however, it is possible that because of the significant paper handling activity that may be associated with a computer room, PM_{10} emissions may be increased at such locations. This potential source should continue to be evaluated as additional BASE data are collected.

Sensitivity Analysis

Six parameters in the equation above were evaluated at reasonable upper- and lower-bound values, while keeping all other parameters at average values. These parameters included the return-air flow rate, test space volume, air exchange rate, filtering efficiency, period of operation, and deposition rate. The sensitivity analysis indicates that the mass-balance model used is not very sensitive to the uncertainty (and potential variability) associated with the return-air flow rate, air exchange rate, test space volume, and period of operation. Filter efficiency and deposition rate, however, do appear to impact the results significantly.

The BASE study does not lend itself well to collecting additional information on these parameters; however, as this analysis indicates, additional research on particle deposition rates indoors and filter efficiencies would be valuable.

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Address correspondence to:

ADAM C. JOHNSTON
ENVIRON Corporation
4350 North Fairfax Drive
Arlington, VA 22203

7 Eutrophication of Coral Reefs

RAFAEL A. OLIVIERI

This report reviews the issue of eutrophication of coral reefs and summarizes some of the most recent advancements on the topic. The goal for the document is to serve as a resource for the staff of the U.S. Environmental Protection Agency (EPA) during development of guidance and regulation for the protection of coral reef ecosystems.

Nixon (1995) defined eutrophication as “an increase in the rate of supply of organic matter to an ecosystem.” Eutrophication is a condition in which high inputs of nutrients trigger massive blooms of phytoplankton cells or macroalgae, with detrimental impacts on the ecosystem. Until recently, eutrophication of marine ecosystems was not a widely recognized phenomenon (Bricker and Stevenson, 1996), but it may be one of the most serious problems affecting the marine environment (NRC, 1993). Even though marine eutrophication research has increased during the last couple of decades, it lags behind the work done and the information amassed for freshwater systems (Vollenweider, 1992; Nixon, 1995).

Since its inception, EPA has primarily concentrated its water-related efforts on freshwater problems. Therefore, EPA’s knowledge of the environmental condition of the coastal waters is less than the knowledge available for estuarine and inland waters. It is not surprising that there is a lack of quantitative guidance criteria for identification and prevention of coastal eutrophication (NRC, 1993).

RAFAEL A. OLIVIERI is currently a 1997-98 AAAS EPA Risk Assessment Fellow. His expertise is in biological oceanography and marine ecology. He holds a Ph.D. in Biology from the University of California at Santa Cruz. During his summer fellowship, he worked in the EPA’s office of Wetlands, Oceans, and Watersheds.

EPA has a mandate under a wide gamut of federal acts to provide guidance and regulations that ensure the environmental protection of coastal waters, including human health and aquatic life. The core of the mandate resides within Sections 301, 319, and 403 of the Clean Water Act (CWA) and in the Coastal Zone Management Act (CZMA) Reauthorization Amendments of 1990. These guidance and regulations developed by EPA are based on the best scientific information available, and address the particular conditions of each ecological system. A guidance criterion for the prevention of eutrophication for a system like the Chesapeake Bay or Long Island Sound would not be adequate for coral reef waters (Johannes and Betzer, 1975; Gabric and Bell, 1993; NRC, 1993).

Coral reefs are a unique type of ecosystem. They are a diverse taxonomic community made up of calcifying marine invertebrates and primary producers dominated by hermatypic (reef-building) corals and calcareous algae (Borowitzka and Larkum, 1986; Hillis-Colinvaux, 1986; Goenaga and Boulon, 1991-92; Björk *et al*., 1995). They have evolved and adapted to marine waters that are very transparent, shallow, warm, and low in nutrient concentration (Porter *et al*., 1994). The total coral reef biodiversity is not well known, but it may be one of the highest on Earth (Reaka-Kudla, 1996; Reaka-Kudla, 1997). In addition, coral reefs are important sites for commercial and recreational fisheries, tourism, protection of coastal erosion, and as a potential source of new biotechnology products. The average global economic value provided by the ecological services of coral reefs is estimated at \$6,075 ha^{-1} yr^{-1} (Costanza *et al*., 1997). For the communities of southern Florida, Hawaii, Puerto Rico, and the U.S. Virgin Islands the value of coral reefs could be orders of magnitude higher.

Nutrients in Marine Environments

The two main nutrients for marine algae, which may cause eutrophication if in high concentration, are nitrogen (N) and phosphorus (P). In the marine environment N and P tend to exist in a 16:1 proportion known as the Redfield Ratio.

Both elements are not active as nutrients in their elemental form. Phosphorus is available to marine primary producers in a dissolved inorganic phase (DIP) as phosphate (PO_4) . Phosphorus can also be found as dissolved organic phosphorus (DOP), particulate organic phosphorus (POP), and particulate inorganic phosphorus (PIP), but these forms are not directly utilized by marine primary producers.

An important difference between N and P cycles is that P does not have an atmospheric gas phase like N (Valiela, 1984). Nitrogen is available to aquatic plants mostly as ammonia (NH_3; here referred to as the total of ammonium plus ammonia), nitrate (NO_3), and to a lesser degree nitrite (NO_2). These forms of nitrogen are commonly referred to as dissolved inorganic nitrogen (DIN). Marine algae can use other forms of nitrogen-like urea and dissolved organic nitrogen (DON) (Dortch, 1990), but these N species are less important for algae metabolism. However, DON is used by bacteria and transformed into the DIN form. Particulate organic nitrogen (PON) cannot be used directly by marine algae but it can be consumed by detritovours and degraded by bacterial action into DIN that could be used by phytoplankton and macroalgae. Nitrogen as N_2 is not taken directly by marine algae but is fixed by some cyanobacteria and transformed into DIN.

Nutrients in Coral Reefs

A fundamental characteristic of coral reef waters is the naturally occurring low nutrient concentrations. Typical NO_3 and NH_3 concentrations are far below 0.5 mM; for phosphate they tend to be below 0.1 mM or undetectable. Low nutrient values maintain very low primary production rates in the water column of coral reef waters and prevent the formation of phytoplankton blooms. In contrast, the benthic component of coral reefs is one of the ecosystems with highest gross production, exceeding 2,500 g C m^{-2} yr^{-1} (Valiela, 1984, and references therein), but lowest net production (D'Elia, 1988; Wiebe, 1988). High production with very low available nutrient is explained by high levels of nitrogen fixation plus very intense nutrient recycling (Corredor and Morell, 1985; D'Elia, 1988; Atkinson, 1987; Johnstone *et al*., 1989; Capone, *et al*., 1992; Shashar *et al*., 1994).

The interactions between corals and their zooxanthellae endosymbionts are responsible for a large portion of the nutrient recycling that occurs in coral reefs. Zooxanthellae is a name given to photosynthetic dinoflagellates that live inside coral tissue in a close biochemical relationship with their host (Muscatine *et al*., 1989, and references therein). Values as high as 90 percent of the zooxanthellae nitrogen demand is reported to be supplied by recycled nutrients (Rahav, 1989). Under natural conditions zooxanthellae are nutrient-limited within corals, particularly by nitrates (Szmant *et al*., 1990, Marubini and Davies, 1996). A nutrient-limited but photosynthetically active zooxanthellae population provides the optimal biological conditions for the coral host to flourish (Jokiel *et al*., 1994). However, without zooxanthellae symbionts the coral host becomes energetically stressed and may eventually die.

Anthropogenic Sources of Nutrients for Eutrophication

The sources of nutrients for eutrophication are classified as point or nonpoint sources based on how they reach affected waters. Point sources are effluents that reach a body of water by pipes, discharge channels or similar structures. They can range from raw sewage and storm water to advance treated water; and they can have an urban, industrial, or agricultural origin. Nonpoint sources, also called diffuse, do not enter the aquatic system by a single site but across a widespread boundary or interphase zone. Nonpoint source nutrients reach the aquatic system as surface runoff, ground water, or atmospheric deposition.

Point sources like sewage effluents from treatment plants were considered the main sources of nutrients causing eutrophication, however, nonpoint sources can be as large or larger contributors of excess nutrients (Olem, 1993). For example, in the Chesapeake Bay, one of the best studied estuaries in the world, nonpoint sources contributed about 77 percent of the total nutrients reaching the Bay (Shuyler, 1993).

Even though point sources can exert constant and chronic pressure on the ecosystem (Kinsey, 1988), they are easier to assess, predict, control, and manage than nonpoint sources (Olem, 1993).

Atmospheric deposition of nutrients in the coastal zone is the least understood nonpoint source process. The knowledge is limited by the paucity of comprehensive data sets. However, the available data suggest that atmospheric deposition may be an important contributor to nutrient loading of coastal zones (Paerl, 1993, 1995; Nixon, 1995; Valigura *et al*., 1996). For example, atmospheric deposition is responsible for more than 20 percent of the total nitrogen that reaches Sarasota and Tampa Bay (references in Valigura *et al*., 1996). The atmospheric deposition of phosphate is usually overlooked because phosphorus does not have a gaseous phase. Phosphate was not discussed in a seminal report titled "Atmospheric Nutrient Input to Coastal Areas: Reducing the Uncertainties" of the National Oceanic and Atmospheric Administration's Decision Analysis Series (Hinga *et al*., 1995). However it is possible that phosphate bound to dust enters the marine system in areas where aeolian deposition of sediments from terrestrial origin is significant (Gabric and Bell, 1993).

Surface runoff and ground water flows from agricultural, urban, and industrial areas are major nonpoint sources of nutrients in the coastal zone (Lewis, 1987; Johansson and Lewis, 1992; Lapointe and Clark; 1992 Gabric and Bell, 1993; Shuyler, 1993; Wagner and Heyl, 1993; Shinn *et al*., 1995; Lapointe and Matzie, 1996; Staver and Brinsfield, 1996). Nutrient loading to the coastal zone depends on the availability of nutrients to be carried by surface and ground waters, as well as watershed characteristics such as size, vegetation cover, land utilization, topography, and soil composition and permeability (Shuyler, 1993). These sources tend to be seasonal because they are influenced by the annual precipitation cycle (Lapointe and Matzie, 1996). This added complexity increases the cost of gathering information, which limits the amount of data available for the proper management of the watershed (Cabe and Herriges, 1992). Therefore, models are frequently used to complement the estimation of concentrations and flows of nutrients from nonpoint sources (Yeh *et al*., 1991; Cabe and Herriges, 1992).

How Eutrophication is Expressed

One of the obvious signals that an aquatic system is eutrophied is an anomalously high increase in phytoplankton biomass. Higher primary-production rates that overcome herbivore-grazing rates and physical dilution allows the accumulation of phytoplankton cells. The increase in phytoplankton biomass has several negative effects for coral reefs. The first one is a rapid nonlinear reduction on available light (Morel, 1988), thus reducing the photosynthesis by zooxanthellae and calcareous algae.

The second is an increase in sedimentation rates. Excess sediments cover and stress the coral polyps and the calcareous algae. Increased sedimentation rates not only affect the adult coral colonies but also reduce larvae recruitment and juvenile survival rates (Wittenberg and Hunte, 1992; Hunte and Wittenberg, 1992; Richmond, 1993). A third effect is higher decomposition rates fueled by the excess organic matter, which reduce dissolved oxygen concentrations (Lapointe and Matzie, 1996). In many instances the increase in phytoplankton population is accompanied by a change in species composition. This switch in community structure has been proposed as an explanation for the increased incidence of harmful algal bloom (Smayda, 1989; 1990). Harmful alga blooms can produce toxins with negative impacts for aquatic life, and that cause serious human illness and even death (Anderson *et al*., 1993; Anderson, 1995; Boesch *et al*., 1997).

Another obvious form of eutrophication is an increase in noncalcareous macroalgae growth. The growth of noncalcareous algae in coral reefs is limited by low nutrient concentration and intense grazing; with excess nutrients noncalcareous macroalgae grow faster than the calcareous algae and coral colonies (Coen, 1988; Morrison 1988; Hackney *et al*., 1989; Delgado and Lapointe, 1994; Björk *et al*., 1995; Tanner, 1995). The uncontrolled growth of noncalcareous algae has similar effects as the increase in phytoplankton blooms: decrease in available light and dissolved oxygen and increase in sedimentation. The coral colonies and calcareous algae can not compete with the noncalcareous algae, resulting in coral reefs being overgrown with noncalcareous algal matts (Smith *et al*., 1981; Dustan and Halas, 1987; Richmond, 1993).

The increase in particulate organic matter coming from sewage effluents, and enhanced organic production, can increase the population of benthic filter feeders and detritovours such as sponges, tunicates polychaetes, and barnacles (Smith *et al*., 1981). This new benthic community can displace the coral colonies and increase the bioerosion of the reef (Smith *et al*., 1981).

Eutrophication also operates at the zooxanthellae level. Excess nutrients increase zooxanthellae growth, which, counterintuitively, is not beneficial for the coral host (Szmant *et al*., 1990; Stimson and Kinzie III, 1991; Jokiel *et al*., 1994; Marubini and Davies, 1996). Under natural conditions zooxanthellae populations are fairly constant and nutrient-limited, particularly by nitrates, within the coral host (Muscatine *et al*., 1989; Bythell, 1990; Szmant *et al*., 1990; Marubini and Davies, 1996). With excess nutrients the zooxanthellae population grows uncontrolled and the balance of the nitrogen-carbon fluxes between the coral host and zooxanthellae is disrupted, resulting in a reduction of calcification and weakening of the coral calcareous skeleton (Stimson and Kinzie III, 1991; Jokiel *et al*., 1994; Marubini and Davies, 1996).

Another form of stress from excess nutrients to coral reef ecosystems is reduction in calcification and carbonate accretion by phosphate poisoning (Simkiss, 1964; Delgado and Lapointe, 1994, and reference therein; Björk *et al*., 1995). For example, phosphate concentrations greater than 3 mM reduced the ratio of cell wall thickness to cell volume in the calcareous encrusting algae (Björk *et al*., 1995). Phosphate poisoning affects both corals and calcareous algae and, in combination with other eutrophication effects, can result in elevated erosion of the coral reef carbonate structure.

Eutrophication conditions debilitate the coral reef ecosystem making it more susceptible to damage by natural stressors. An increase in incidence of coral diseases and reduced recovery after hurricanes had been partly attributed to damage caused by multiple human impacts, including excess nutrients (Richmond, 1993, and reference therein).

Mitigation

To prevent eutrophication, it is more important to reduce the available nutrients in the receiving waters than the total nutrient loading (Guillaud *et al*., 1992). Low available nutrients can be attained by reducing the nutrient input at the source and reducing nutrient concentration and residence time in the receiving waters.

Lower nutrient inputs could require major economic investments to the sanitary infrastructure or low-cost modification to the general environment and human practices. For example, for a major urban area, reducing the nutrients in sewage waters may require upgrading water treatment plants to an advanced tertiary process. This could represent an economic cost that must be carefully weighed against the possible benefit from the modifications. The reduction of nutrients in urban runoff may be achieved in a cost-efficient way by improving the amount and quality of the vegetation cover of the urban landscape (Hipp *et al*., 1993) and by using flood retarding basins as wetland restoration areas (Breen *et al*., 1994). In agricultural areas, nonpoint sources could be reduced by switching to more sustainable and best-management practices (Hatfield, 1993; Logan, 1993).

Nutrient concentration and residence time in receiving waters can be reduced by increasing the dilution and water circulation (Guillaud *et al*., 1992). An example is changing sewage effluents outflow sites to more open water areas with high hydrodynamics. Minimal impacts have been observed in areas where sewage effluent to coral reefs are located in open waters with high circulation (Dollar, 1994; Griggs, 1994; 1995). The cost of this type of modification is site-specific, and again should be weighed against the potential benefits. To reduce the danger of eutrophication in coral reefs, Bell (1992) proposed nutrient concentration thresholds of about 1mM for DIN and about 0.1- 0.2 mM for PO_4. For chlorophyll (as a measure of phytoplankton biomass) the proposed threshold concentration to consider a site eutrophied was set at about 0.5 mg m^{-3} (Bell, 1992).

To progress toward any effective solution first requires educating the general public and business community on the cost and benefits of eutrophication control (Johannes, 1975; Hatfield, 1993; Shuyler, 1993; Nixon, 1995).

Recommendations

- Convene a workshop for academia and government representatives to develop a protocol for a national coral reef inventory. The inventory would serve as a tool to monitor and evaluate present and future trends in coral reef conditions, and to differentiate between natural and anthropogenic influences.

- Do not use nutrient concentrations as the metric to define eutrophication. Instead, as recommended by Bell (1992), use a chlorophyl concentration of 0.5 mg m^{-3} to define eutrophication in coral reefs.

- Ensure that coastal waters are included in watershed management plans.

- Integrate restoration of coastal wetlands and wetland mitigation practices with the control of sewages and nonpoint sources of nutrient inputs.

- Consider the physical dynamics of the receiving water in addition to the nutrient loading when evaluating the risk of eutrophication. Blooms of phytoplankton and algae will depend more on the concentration of nutrients and resident time than on the total loading (Guillaud *et al*., 1992).

- Calculate the final concentration of nutrients in the receiving waters and report those values in the units used in ocean science, which are mg-at l^{-1} or mM or mmol m^{-3}. Reporting values in total pounds or kilograms for a unit of area or time is important information, but not the most useful when deciding the risk of eutrophication.

- Increase the resolution of water monitoring programs, since it has been demonstrated that quarterly or biweekly sampling can miss dramatic anthropogenic nutrient inputs (Tomasko *et al*., 1996).

- Develop more aggressive outreach and educational programs that teach the general public the biological, economic, and cultural value of coral reefs and how they are affected by human activities.

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Address correspondence to:

RAFAEL A. OLIVIERI
U.S. Environmental Protection Agency
National Center for Environmental Assessment
401 M Street NW (8623)
Washington, DC 20460

8 An Evaluation of the Potential Impacts of Increased Nutrient Fluxes Across the Air-Sea Interface and Neuston Response

Darren G. Rumbold

The air-sea interface is a concentration point for various natural and anthropogenic materials, including organic and inorganic nutrients (for reviews, see Hardy, 1982; GESAMP, 1995). Neuston, a highly diverse and specialized planktonic community, occurs at the surface in or near this nutrient film. Many ecologically or economically important species of fishes and invertebrates are meroneustonic, spending their early life stages at the surface. The juxtaposition of materials and neuston at this interface allows for a highly productive open system that plays a role in biogeochemical cycling. However, concentration at this interface also increases the likelihood of neuston exposure to a variety of stressors.

Accordingly, a study was undertaken to assess the relative risks from these stressors. This assessment follows the problem-formulation phase of the U.S. Environmental Protection Agency's (EPA's) recently proposed ecological risk assessment guidelines (U.S. EPA, 1996). The goal of problem formulation is to generate and evaluate preliminary hypotheses about why ecological effects have occurred, or may occur, from human activities.

DARREN G. RUMBOLD is currently unaffiliated. His expertise is in ecotoxicology. He holds a Ph.D. in Marine Biology and Fisheries from the University of Miami. During his AAAS fellowship, he worked at the National Center for Environmental Assessment Statutory Authority.

The ecosystem at risk is characterized, assessment endpoints are defined, and sources and pathways of potential stressors are identified. Finally, risk hypotheses are formulated based on a general conceptual model. This document summarizes the findings and recommendations of a problem formulation that considers potential effects of anthropogenically derived nutrients to the neuston.

Statutory Authority

A variety of pollution control programs implemented by EPA affect coastal waters, including the issuance of National Pollutant Discharge Elimination System permits, development of water quality criteria, review of State programs, and monitoring and demonstrating projects. Statutory authority for these programs is included under the Clean Water Act, as amended (33 U.S.C. §1251 et seq.); the Coastal Zone Act Reauthorization Amendments of 1990 (16 U.S.C. §1455b et seq.); and the Marine Protection, Research, and Sanctuaries Act of 1972, as amended (16 U.S.C. §1431 et seq.). To date, EPA's involvement in the microlayer and neuston has been limited to a small number of extramural grants and research associated with the short-lived Incinerator-at-Sea program.

Ecosystem Characterization

To assess anthropogenic effects to the neuston, one must first understand the unique physical and chemical environment of the air-sea interface and its role in neuston ecology. Naturally occurring surface-active materials often concentrate in a film or microlayer at the air-sea interface. While early work on the microlayer's composition emphasized lipids as the primary constituent, more recent studies have found that carbohydrates and proteinaceous compounds dominant. However, much of the organic fraction of the surface microlayer remains uncharacterized and is likely humic materials (for review, see Hunter and Liss 1981). The microlayer is also naturally enriched, relative to underlying waters, in inorganic nutrients.

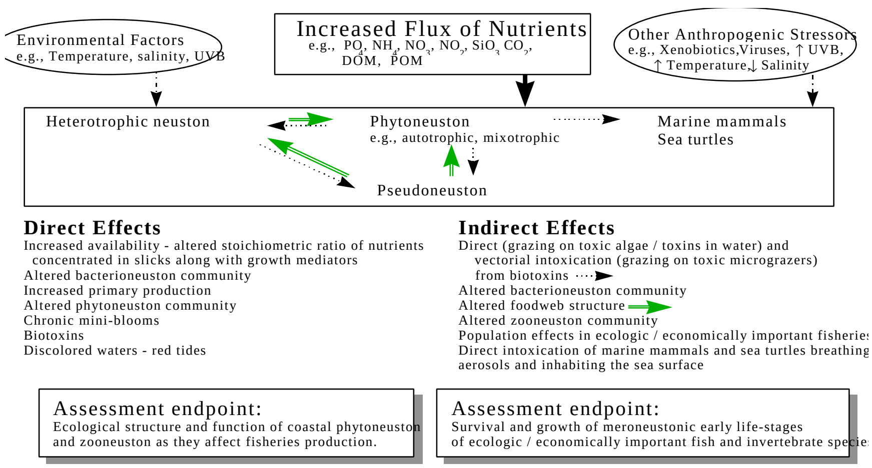
Most of this material is biogenic, either from in situ production or from terrestrial sources, and is concentrated in the microlayer from bulk seawater transfer (e.g., diffusion, upwelling, rising gas bubbles), by riverine discharges, or from atmospheric deposition. Because of its position at the air-sea interface, the microlayer is exposed to extremes in wind stresses, solar radiation, temperature, and salinity.

This microlayer represents a nutrient-rich medium for a diverse neustonic community composed of bacteria, fungi, microalgae (including many bloom-forming species), cnidarians, mollusks, copepods, isopods, and tunicates. The microlayer also functions as a nursery for embryos and larvae of fishes, shellfishes, and crustaceans (for reviews, see Zaitsev, 1971; Hardy, 1982). The species assemblage in the neuston often is distinctly different from that found in underlying waters (Zaitsev, 1971; GESAMP, 1995, and references therein).

Management Goals, Assessment Endpoints, and a Conceptual Model

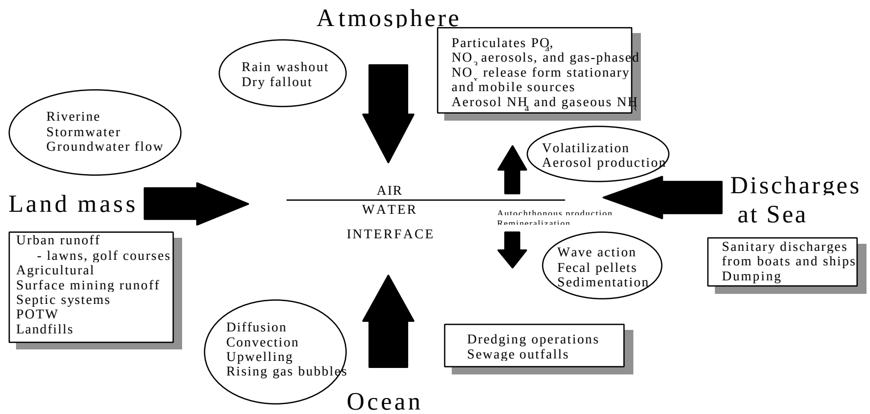
To provide direction and boundaries for the risk assessment, it is important to clearly articulate management goals early in the assessment process. The draft management goal for the current assessment is to minimize the adverse effects that anthropogenically derived nutrients have on the coastal ecosystem and the neustonic community in particular. The environmental value to be protected is defined by the assessment endpoint, which should be ecologically relevant, susceptible to the stressors of concern, and representative of management goals (U.S. EPA, 1996). An assessment endpoint proposed for the current study is the survival and growth of meroneustonic early life stages of ecologic or economically important fish and invertebrates species. However, recognizing the complex nature and interdependence within this system, the phyto- and zooneuston on which these resource populations depend must also be protected and thus are included as a second assessment endpoint (Figure 1).

Figure 1. Conceptual model of stressors at the sea-surface microlayer and effects to neuston.



The conceptual model proposed in Figures 1 and 2 is purposefully general and broad in scope, identifying as many potential relationships as possible. Simply stated, neuston is particularly susceptible to certain risks because of its position at or near the air-sea interface where multiple stressors impinge, flux, and often concentrate (Figure 1). The goals of a formal ecological risk assessment are to compile and sort through these stressor-effect scenarios and to prioritize risks. Although a limited number of studies have examined the risks from xenobiotics, and increased sea-surface temperature or increased UV-B (ultraviolet-B) (GESAMP, 1995, and references therein), the possible effects to the neuston of altered nutrient fluxes have been largely overlooked. At the same time, recent assessments of anthropogenic nutrification of coastal waters have not addressed the problem in terms of impacts to the neuston.

Figure 2. Conceptual model: nutrient pathways and sources at air-water interface.



There are many anthropogenic sources of nutrients to coastal waters and, as shown in Figure 2, the influx and efflux of much of this material are across the air-sea interface. Moreover, these anthropogenic nutrients are subject to the same processes that concentrate natural materials in the microlayer. Indeed, limited studies have shown that the sea-surface microlayer collected adjacent to urban areas differs from reference samples in terms of the composition and concentration of a variety of materials (for review, see GESAMP, 1995).

A review of each of the risk hypotheses that follow from this conceptual model is beyond the scope of this summary report, but an example of one extreme outcome is that a monospecific bloom of a noxious phytoneuston might occur as a direct result of the altered nutrient mixture. Numerous studies have attempted to link nutrient inputs with the increased frequency and severity of harmful algal blooms (HABs). However, these studies considered this phenomenon a plankton response and not a neuston response, despite early recognition that some bloom-forming taxa (e.g., dinoflagellates) concentrate at the surface (Ryther, 1955).

As shown in Figure 1, even mini-blooms of a noxious algal species may potentially produce several indirect effects including altering the food web structure or widespread intoxication from biotoxins (for review of impacts to plankton, see Smayda, 1991). The latter threat is particularly significant to neuston in light of recent evidence that suggests biotoxins can concentrate in the microlayer (Rumbold, 1996).

Findings and Recommendations

While major data gaps and uncertainties exist, available information clearly shows that the neustonic community is potentially at risk from numerous stressors. Results from this assessment suggest that examination from a microlayer perspective would yield a better understanding of the processes associated with certain HABs. This conclusion is consistent with the issues and research needs identified recently by a panel of experts on HABs (Anderson, 1995).

Because impacts to fisheries recruitment represent a threat to the sustainability of U.S. marine resources, it is recommended that the assessment endpoints proposed in this report be considered in future ecological risk assessments of stressors to coastal ecosystems. Obviously, future assessments would be more effective in terms of management options if they were geographically focused and relevant to regional or local stressors and resource populations. It is hoped that this report may serve as the initial scoping process to encourage further discussions concerning risks to the neustonic community.

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Address correspondence to:

DARREN G. RUMBOLD
9686 SW 2nd Street
Boca Raton, FL 33428

9 The Drinking Water Paradigm for Environmental Monitoring for Public Access and Community Tracking (EMPACT)

DARWIN L. SORENSEN

President Clinton has directed the Environmental Protection Agency (EPA) to work with State, federal and local agencies to establish a right-to-know network for key environmental health indicators for air, land, and water. Information is to be provided to citizens in a timely way so that families can make informed choices that affect their health (Anonymous, 1996). In response to this direction, EPA Administrator Carol Browner and Assistant Administrator Fred Hansen announced the formation of the Environmental Monitoring for Public Access and Community Tracking (EMPACT) program in March 1997. EMPACT was charged with incorporating technology solutions for real-time environmental measurements; facilitating public access to environmental information that is easily understood; providing effective tools for communicating, interpreting, and applying environmental data and information; establishing partnerships with States and communities to ensure that the information is useful and timely; and developing a community-oriented framework that provides the ability to aggregate information on a local, regional, and national scale. Seventy-five or more metropolitan areas will be chosen as EMPACT cities (Browner and Hansen, 1997).

DARWIN L. SORENSEN is a research associate professor at the Utah Water Research Laboratory at Utah State University in Logan, Utah. His expertise is in environmental microbiology. He holds a Ph.D. in microbiology from Colorado State University. During his AAAS fellowship, he worked in the U.S. EPA Office of Research and Development.

The nature of telephone calls to EPA's Safe Drinking Water Hotline, a recently completed survey (Hurd, 1997), and other literature (Canter *et al*., 1992-93; Vining, 1989) suggest that people are concerned about the quality of their drinking water and want to have access to information about it. Drinking water can be a significant route of exposure to pathogens and pollutant chemicals. An effective, mature, and highly regulated public drinking water treatment and distribution industry exists in the United States to protect against these hazards. This industry generates large amounts of water quality data. Water quality is monitored during the water treatment process to comply with State and federal monitoring and reporting regulations. In many systems, some of these data (e.g., turbidity and residual chlorine) are generated electronically using sensors in water treatment process lines or in the distribution system and are available for communication in real time. Other data are generated in laboratories and become available over longer periods. Bacteriological data (e.g., coliforms) become available on a frequency ranging from daily to monthly depending on the size of the population served by the distribution system. Data on nitrates, heavy metals, pesticides, and volatile organic compounds for example may be reported on a frequency ranging from one per month to one per several years depending on the population served and the history of occurrence of regulated contaminants in the water. Irrespective of the data collection interval, technology exists to make these data available to the public as soon as they are generated.

Institutional Policy Considerations

EMPACT will explore opportunities with water treatment and distribution organizations to voluntarily release water quality information to the public in real time or near-real time. This implies that the release of information will be controlled by the policies and procedures of each individual treatment and distribution organization.

Costs associated with implementation of EMPACT for drinking water will be associated principally with planning and preparation, setup and maintenance, and community involvement and trust building.

These costs will vary among communities and utilities depending on the capacity of existing organizations and technology to absorb EMPACT functions.

Community Involvement

Perhaps the most challenging aspect of the EMPACT drinking water program will be presenting the needed information appropriately and providing the necessary explanations so the data can be interpreted and used properly to improve environmental health. Most individuals want to know simply whether or not their water is safe, but many would also like to know that the data supporting this indication are readily available to them or their expert representatives (Hurd, 1997).

Environmental managers in both the public and private sectors find that enhancing community involvement helps make programs acceptable to the community. Community involvement builds trust. In the EMPACT program, perhaps the greatest need for community involvement is in determining what the community's information needs are and what the presentation format(s) should be. This can be done in informal meetings, by letters or surveys, and by organizing advisory committees with stakeholders and representatives from established community organizations.

For the information system to build and retain trust and acceptance, it is important to have ongoing, community-based review and oversight of the program. The organization should allow evaluation of the program with feedback to leadership on a regular basis (Benjamin and Belluck, 1990). Community involvement may also include integrating EMPACT into local emergency communications procedures.

Example Systems in the Washington, DC-MD-VA-WV Primary Metropolitan Statistical Area

The Washington-Baltimore Consolidated Metropolitan Statistical Area (CMSA), as defined by the Office of Management and Budget, has been nominated to be an EMPACT city.

The District of Columbia, with a population of about 550,000, and Myersville, Maryland, which supplies drinking water to about 900 people through a distribution system with approximately 410 connections, are both part of this CMSA and were selected as examples to highlight the opportunities and challenges facing EMPACT implementation for drinking water quality. These "extremes" in size illustrate the similarities and differences that may exist in systems of widely varying production volume, financial resources, and human resources within a given EMPACT metropolitan area. A similar range of sizes of water utilities is anticipated within most metropolitan areas.

The District of Columbia receives approximately 130 million gallons of drinking water per day through the District of Columbia Water and Sewer Authority (WASA) distribution system. WASA buys treated water from the Washington Aqueduct Division, Baltimore District, U.S. Army Corps of Engineers (Aqueduct). Treated Potomac River water enters the distribution system from the Aqueducts's Dalecarlia and McMillan treatment plants. Water from either plant may flow into any part of the distribution system. The residence time for water in the distribution system averages approximately 1.5 days and ranges up to 4 days (U.S. Army Corps of Engineers, 1991; T. P. Jacobus, Aqueduct, personal communication, July 3, 1997). WASA operates and maintains the distribution system, collects fees for water use, and reports water quality monitoring data to EPA. WASA has a public relations department to respond to requests for information from the public.

A schematic illustration of the treatment process and selected water quality data generation points at the Dalecarlia plant are shown in Figure 1. At the Aqueduct treatment plants, filtered water turbidity, treated water turbidity, pH, residual chlorine, and fluoride concentrations are monitored continuously and the data are processed by a Supervisory Control and Data Acquisition (SCADA) system in real time. These and other process data can be displayed graphically by the SCADA system to show current and recent (hours to days) historical data. These data are available instantaneously and could be made accessible to the public over telephone lines, the Internet, or by radio or microwave transmission.

Figure 1. Schematic illustration of the Washington Aqueduct Dalecarlia water treatment plant process showing water quality data generation points.

Questions about the value of real-time information of this kind in informing individual, environmental health-related decisions may best be answered by representatives of the community.

While real-time data communication is technologically feasible, the experience of Aqueduct and WASA management personnel caused them to react with caution, concern, and an informal policy against making such data available. They felt that the water quality data are public information and that they had "nothing to hide," but they were, in general, concerned about the costs of establishing and operating a public access data system and about the quality or effectiveness of interpretive information and risk communication accompanying the data.

Myersville and some adjoining residential areas receive drinking water from springs, two wells, and Little Catoctin Creek. Water from one well enters the distribution system after receiving only disinfection treatment with chlorine. The balance of the water receives conventional treatment similar to that illustrated in Figure 1 but on a much smaller scale. The Myersville water treatment plant operations are automated and the plant operates unattended most of the time. The plant does not use a SCADA system, but turbidity and residual chlorine concentrations in the treated water are continuously monitored electronically and recorded on paper charts. Given the appropriate transducers, these data could be communicated to the public in real time.

The Myersville water treatment plant is operated by a private contractor whose personnel spend approximately 1 hour each day at the plant. The contractor's personnel anticipate that inquiries about drinking water quality will be directed to the city clerk or to the Maryland Department of the Environment, Public Drinking Water Program. The city clerk's office is open for business in the mornings, 3 days each week. Meeting EMPACT's objectives for Myersville and similar small water systems would require investment in communications technology, personnel time, and community involvement.

Recommendations

The drinking water portion of the EMPACT program can be focused by learning community information needs and wants from focus groups, advisory committees, and surveys, and then designing the program to meet these needs and wants. Identifying common desires among communities can help make the drinking water EMPACT planning, design, and development processes more efficient. EPA may address utilities' concerns by providing reliable information on program costs including personnel involvement. Development of EMPACT public relations guidance might also be beneficial to drinking water utilities. Guidance on mechanisms and formats of information presentation and program organization, including community involvement, oversight, and review, may also encourage water utilities to be involved in EMPACT.

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Address correspondence to:

DARWIN L. SORENSEN
Utah State University
College of Engineering
Utah Water Research Laboratory
Logan, UT 84322-8200

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